

Applications of Accelerators

Accelerator and Particle Physics at A-Level
APPEAL

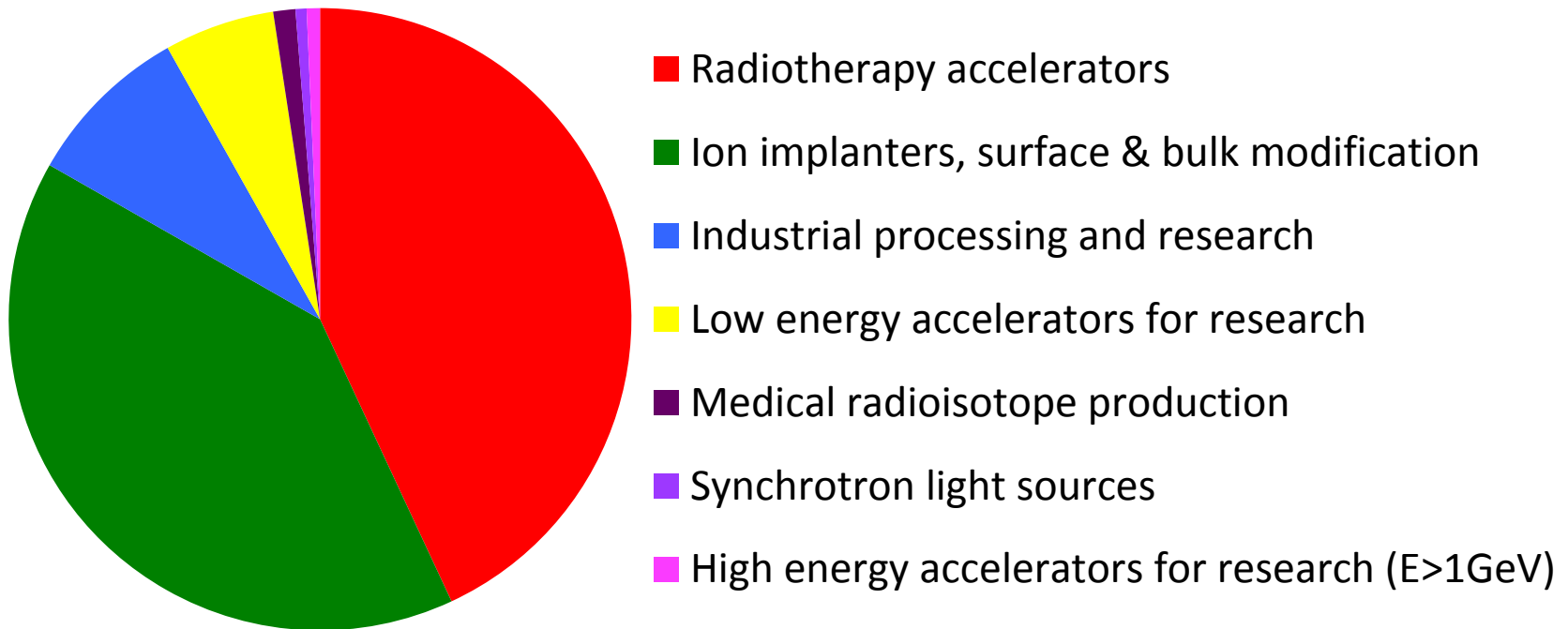
Oxford University, June 11, 2016.

Dr. Suzie Sheehy

University of Oxford and ASTeC/STFC/RAL

- *“A beam of particles is a very useful tool...”*

-Accelerators for Americas Future
Report, pp. 4, DoE, USA, 2011



There are roughly 35,000 accelerators in the world
(Above 1 MeV...)

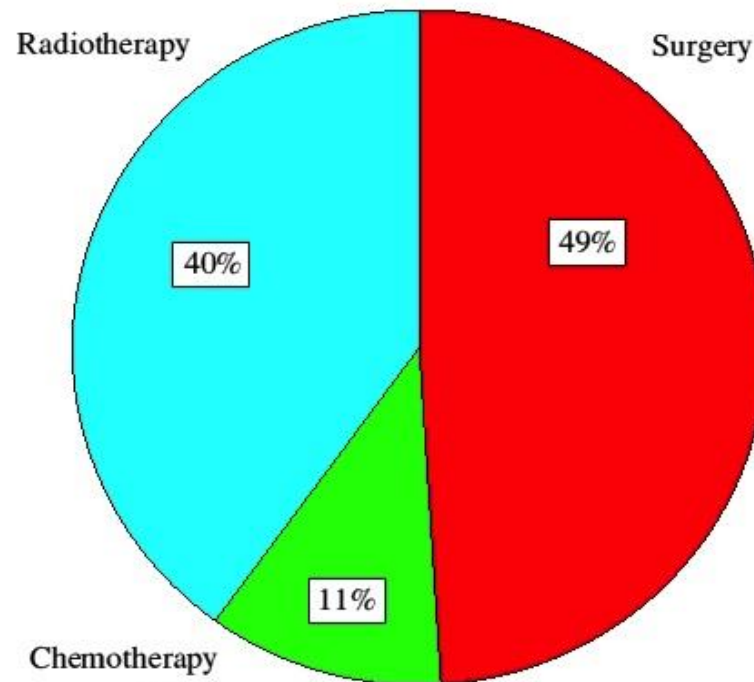
Outline

1. Medical imaging and treatment
2. Industrial uses of accelerators
3. Synchrotron light sources
4. Neutron sources
5. Energy and security applications
6. Historical & cultural applications

1. Medical Applications

- Around 1/3 of people in the will die from cancer...
- But diagnosis is no longer a death sentence!

Patients cured by the major cancer treatment modalities



Chemotherapy
- alone
- with surgery
- with radiotherapy

Reference
Cancer Services Collaborative 2002
www.nhs.uk/npat

X-ray radiotherapy

Linac

Foil to produce x-rays

Collimation system

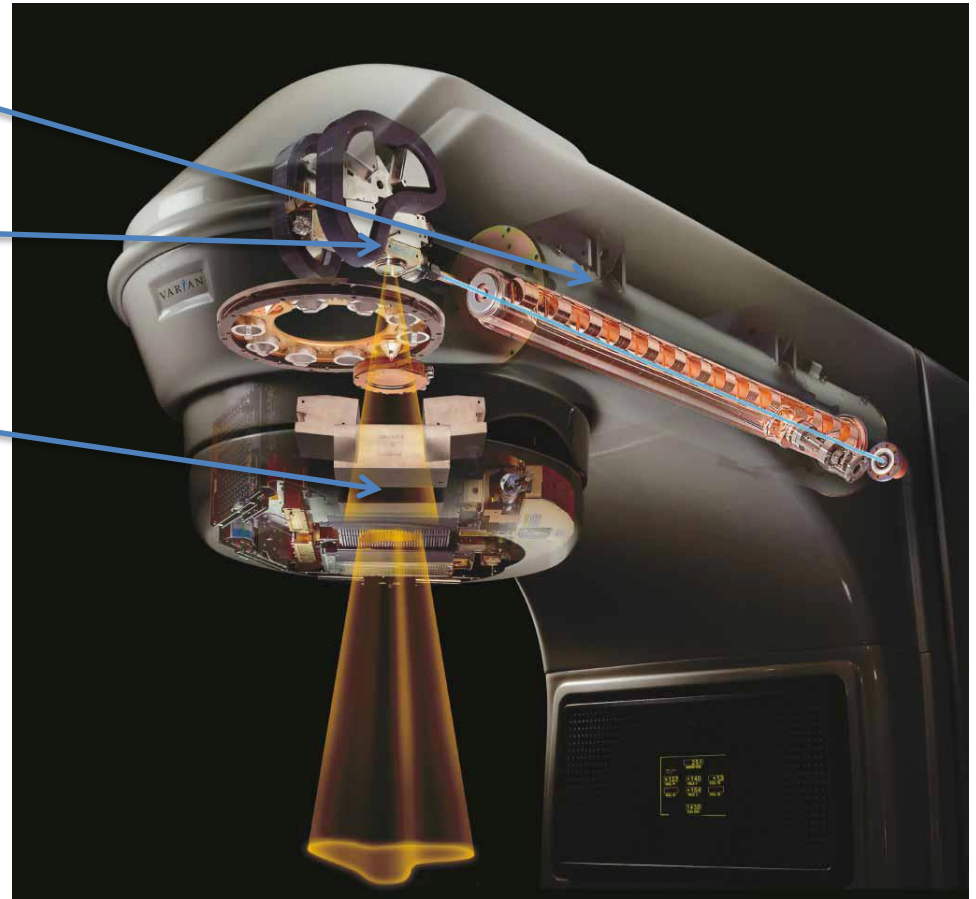
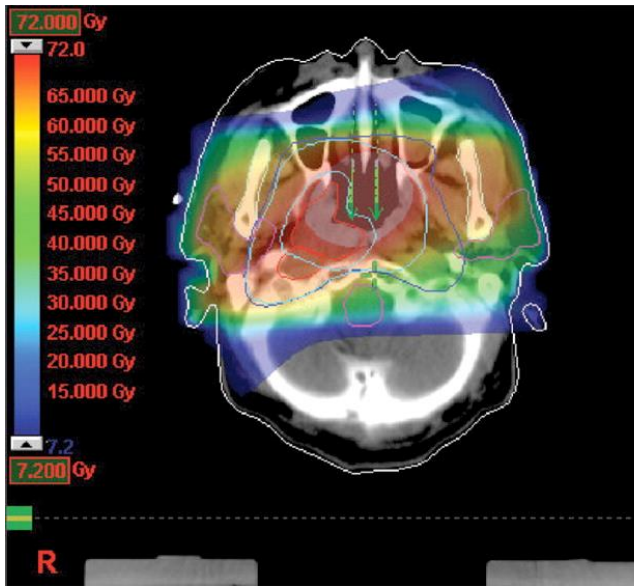


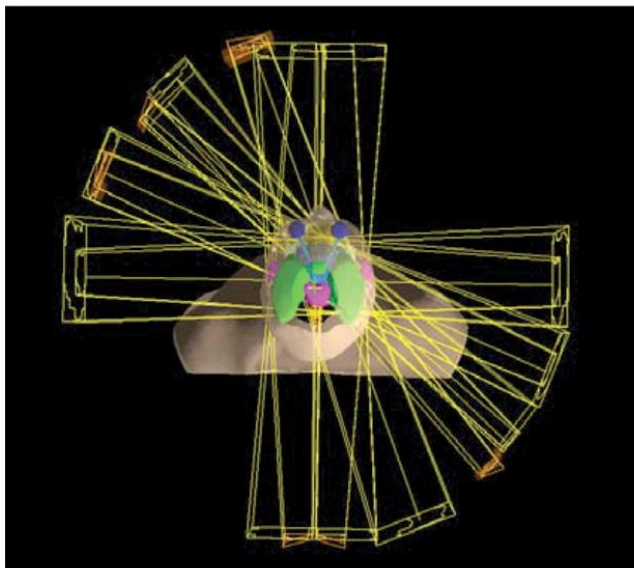
Image: copyright Varian medical systems



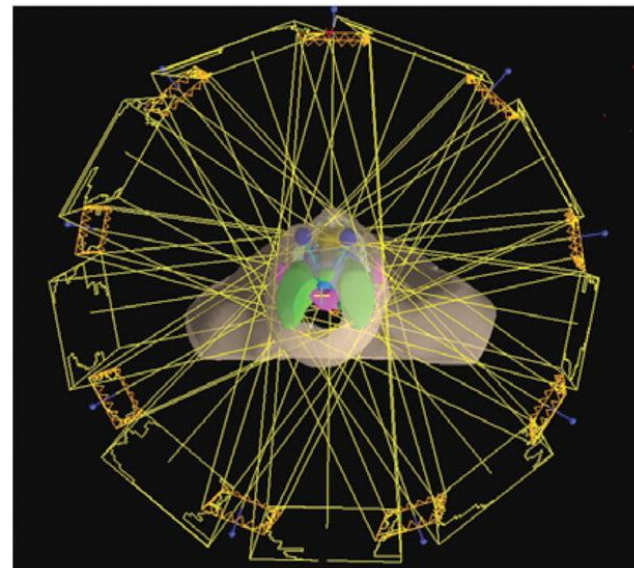
(a)



(b)

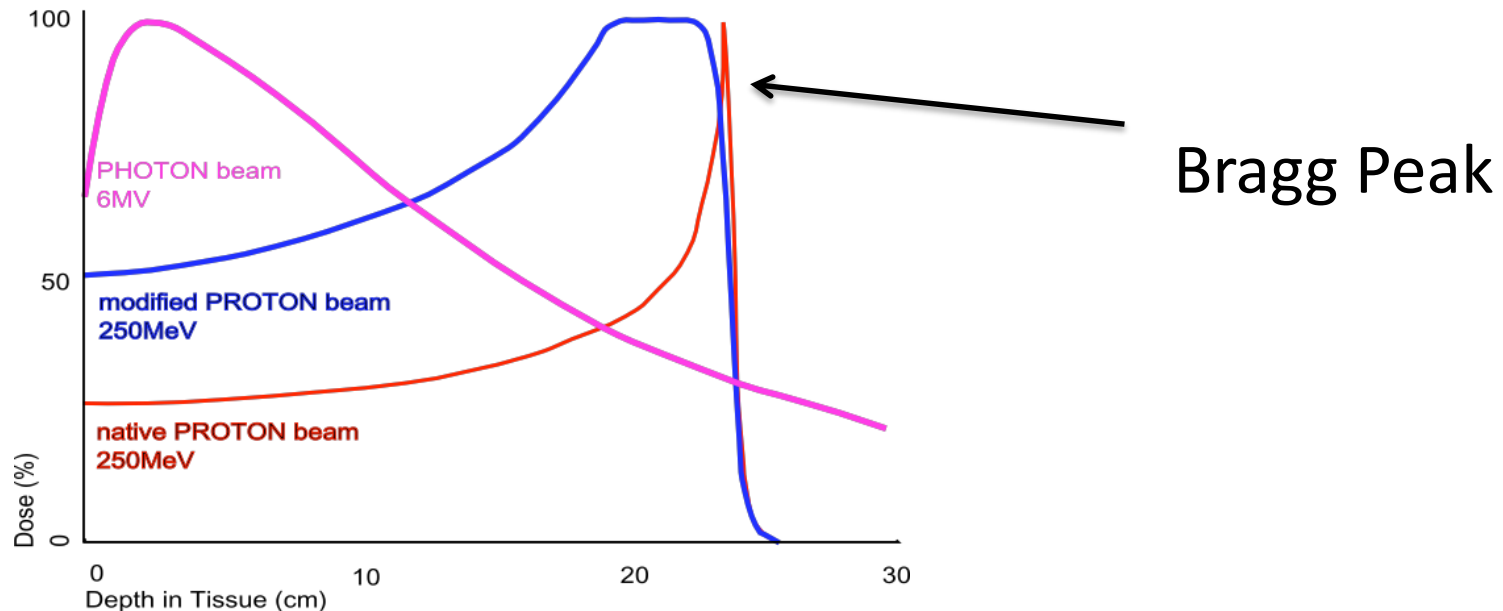


(c)



(d)

Charged Particle Therapy

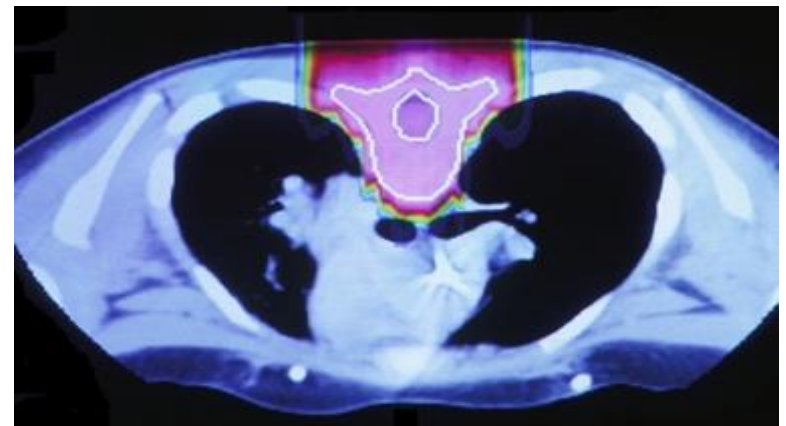
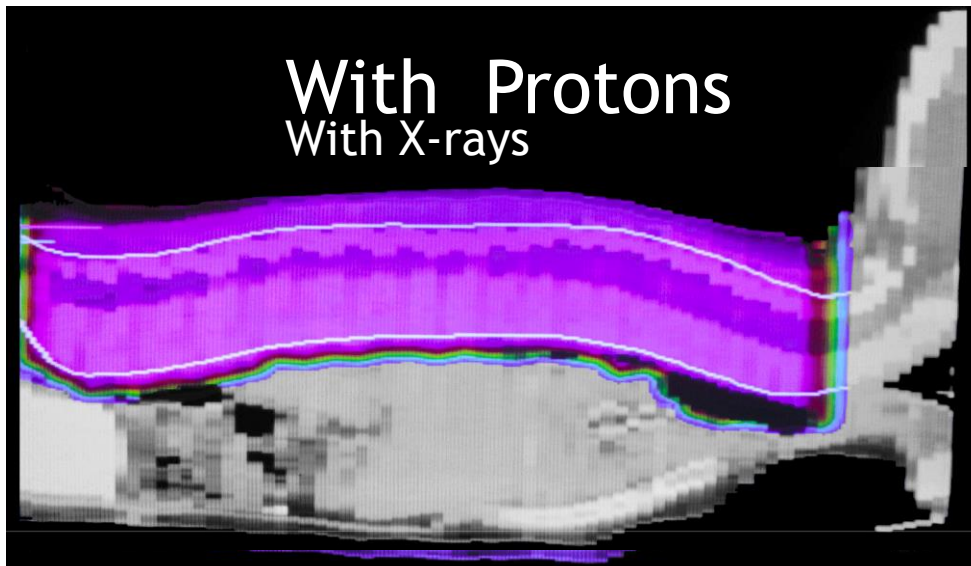


- Greater dose where needed
- Less morbidity for healthy tissue
- Less damage to vital organs

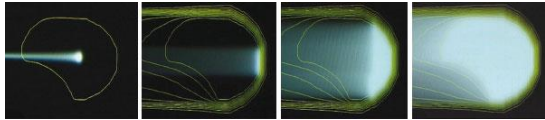
Proton therapy

– “Hadron therapy” = Protons and light ions

- Used to treat localised cancers
- Less morbidity for healthy tissue
- Less damage to vital organs
- Particularly for childhood cancers



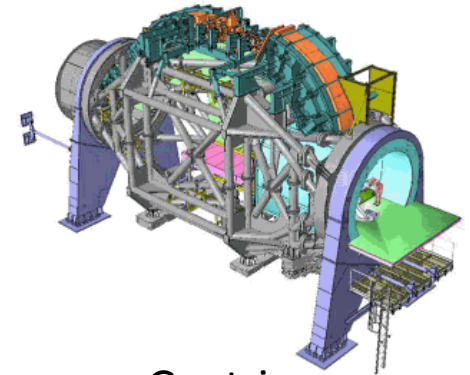
A few developments



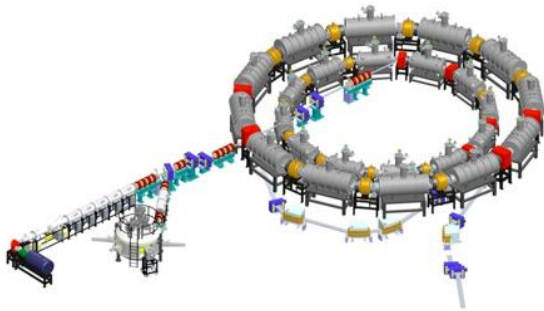
Spot Scanning



Proton Radiography



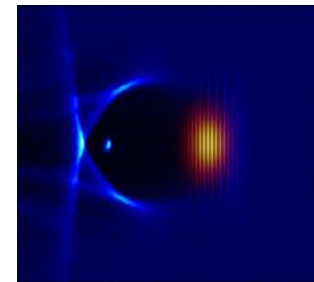
Gantries



FFAG Accelerators



Dielectric Wall Accelerators

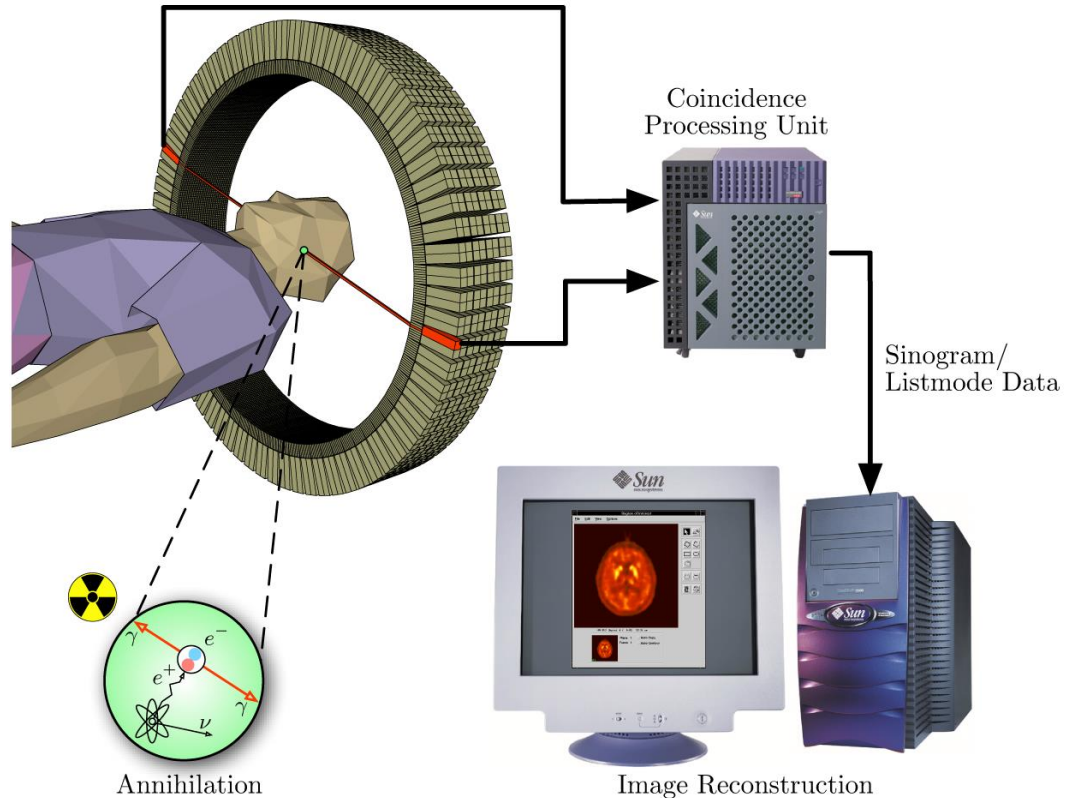


Laser Plasma Accelerators

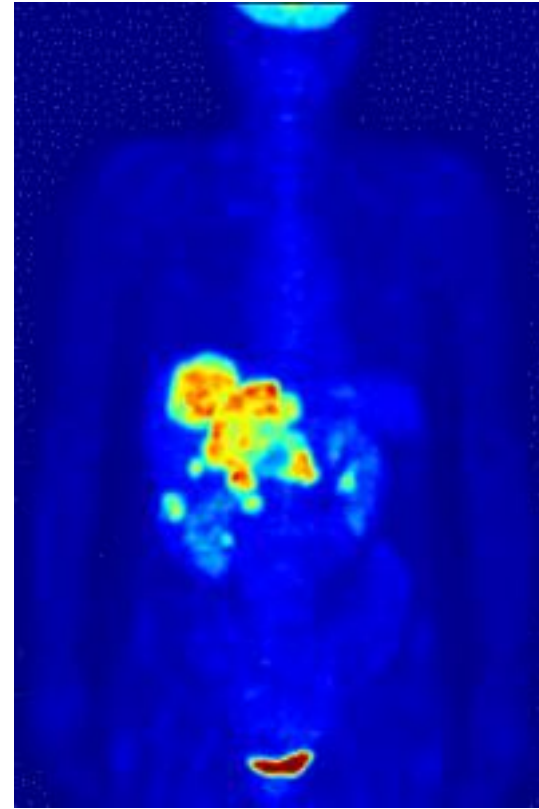
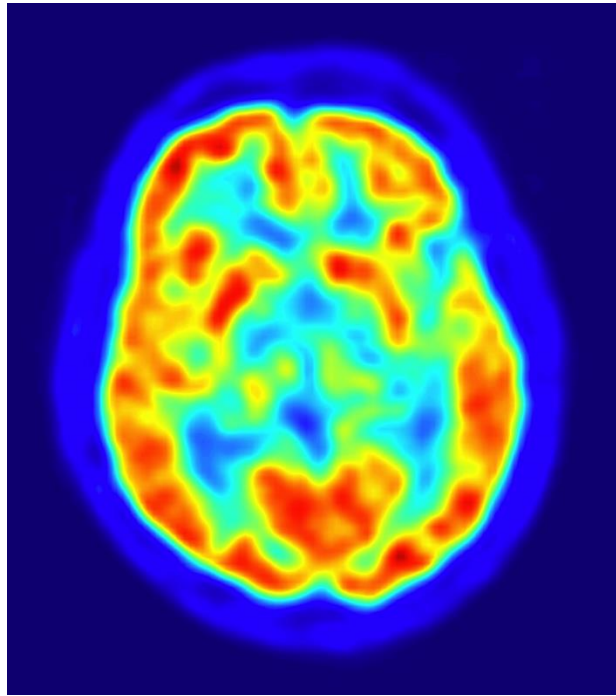
HEP community can contribute accelerators AND other expertise!

Radioisotope production

- Accelerators (compact cyclotrons or linacs) are used to produce radio-isotopes for medical imaging.
- 7-11MeV protons for short-lived isotopes for imaging
- 70-100MeV or higher for longer lived isotopes



- Positron emission tomography (PET) uses Fluorine-18, half life of ~ 110 min



- Fluorodeoxyglucose or FDG carries the F18 to areas of high metabolic activity
- 90% of PET scans are in clinical oncology

Radiopharmaceuticals

p, d, 3He, 4He
beams

Isotopes used for PET, SPECT and
Brachytherapy etc...

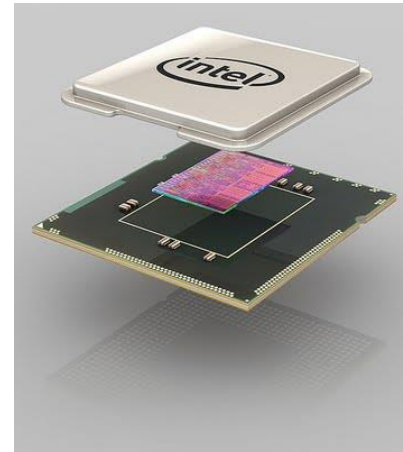
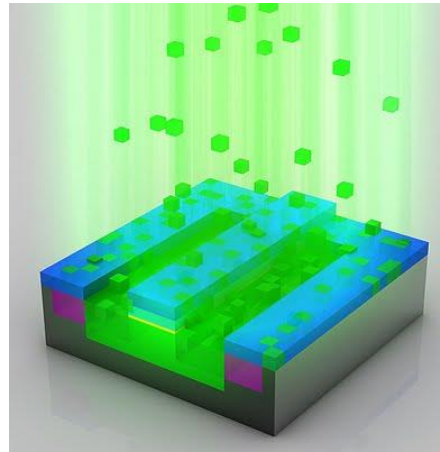
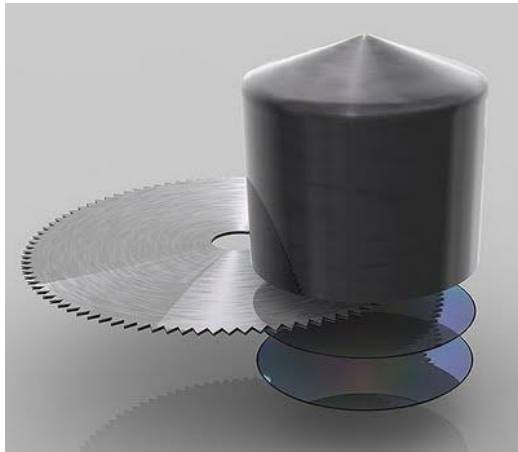


TABLE 2.1. THE RADIOISOTOPES THAT HAVE BEEN USED AS TRACERS IN THE PHYSICAL AND BIOLOGICAL SCIENCES

Isotope	Isotope	Isotope
Actinium-225	Fluorine-18	Oxygen-15
Arsenic-73	Gallium-67	Palladium-103
Arsenic-74	Germanium-68	Sodium-22
Astatine-211	Indium-110	Strontium-82
Beryllium-7	Indium-111	Technetium-94m
Bismuth-213	Indium-114m	Thallium-201
Bromine-75	Iodine-120g	Tungsten-178
Bromine-76	Iodine-121	Vanadium-48
Bromine-77	Iodine-123	Xenon-122
Cadmium-109	Iodine-124	Xenon-127
Carbon-11	Iron-52	Yttrium-86
Chlorine-34m	Iron-55	Yttrium-88
Cobalt-55	Krypton-81m	Zinc-62
Cobalt-57	Lead-201	Zinc-63
Copper-61	Lead-203	Zirconium-89
Copper-64	Mercury-195m	
Copper-67	Nitrogen-13	

2. Industrial accelerators

Ion implantation



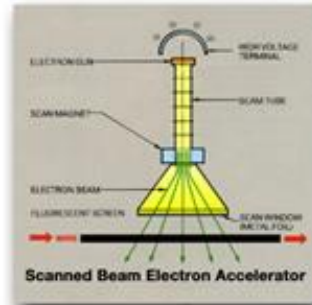
Images courtesy of Intel

- Electrostatic accelerators are used to deposit ions in semiconductors.

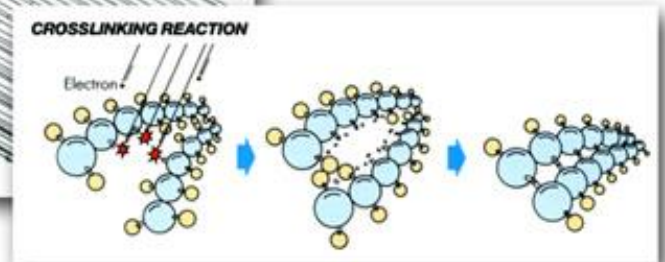
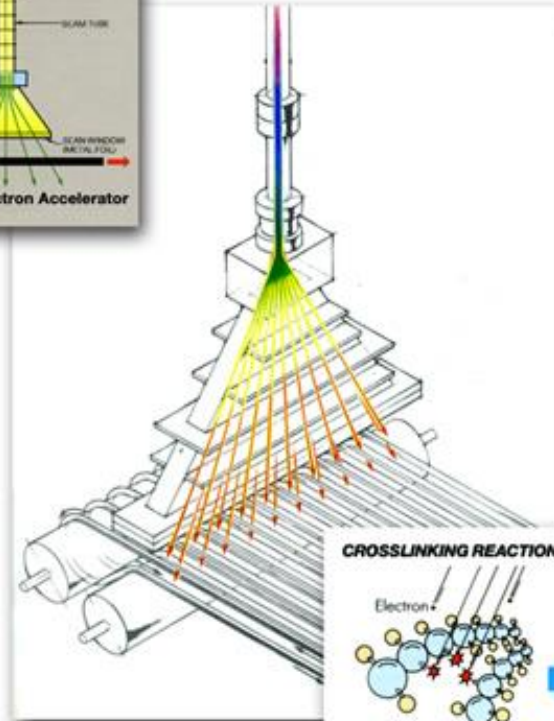
Electron beam processing

In the US, potential markets for industrial electron beams total \$50 billion per year.

- 33% Wire cable tubing
- 32% Ink curing
- 17% shrink film
- 7% service
- 5% tires
- 6% other



<http://rsccnuclearcable.com/capabilities.htm>



When polymers are cross-linked, can become:

- stable against heat,
- increased tensile strength, resistance to cracking
- heat shrinking properties etc

Equipment sterilisation

Manufacturers of medical disposables have to kill every germ on syringes, bandages, surgical tools and other gear, without altering the material itself.

E-beam sterilisation works best on simple, low density products.

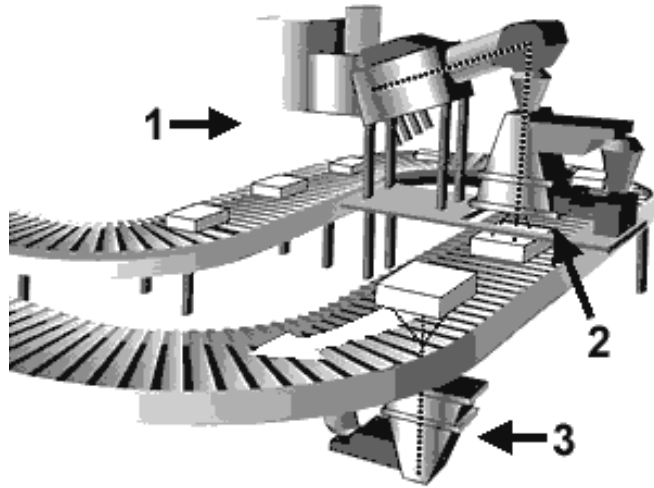
Advantages: takes only a few seconds (gamma irradiation can take hours)

Disadvantages: limited penetration depth, works best on simple, low density products (syringes)



The IBA rhodotron – a commercial accelerator used for e-beam sterilisation

Food irradiation



‘Cold pasteurisation’ or ‘electronic pasteurisation’

Uses electrons (from an accelerator) or X-rays produced using an accelerator.

The words ‘irradiated’ or ‘treated with ionising radiation’ must appear on the label packaging.

In the US all irradiated foods have this symbol



Foods authorised for irradiation in the EU:



Lower dose

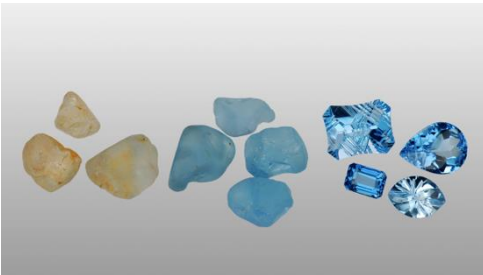
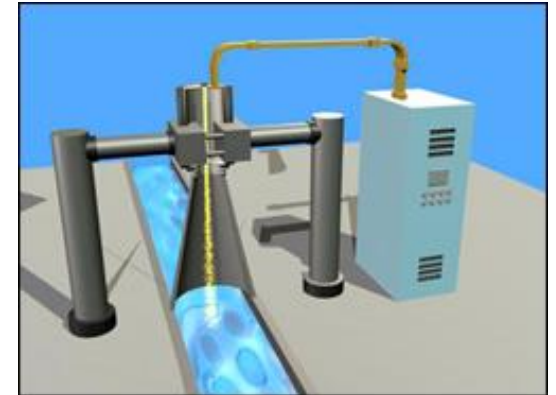


Higher dose

Other uses in industry...

- Hardening surfaces of artificial joints
- Removal of NO_x and SO_x from flue gas emissions
- Scratch resistant furniture

Treating waste water or sewage
Purifying drinking water



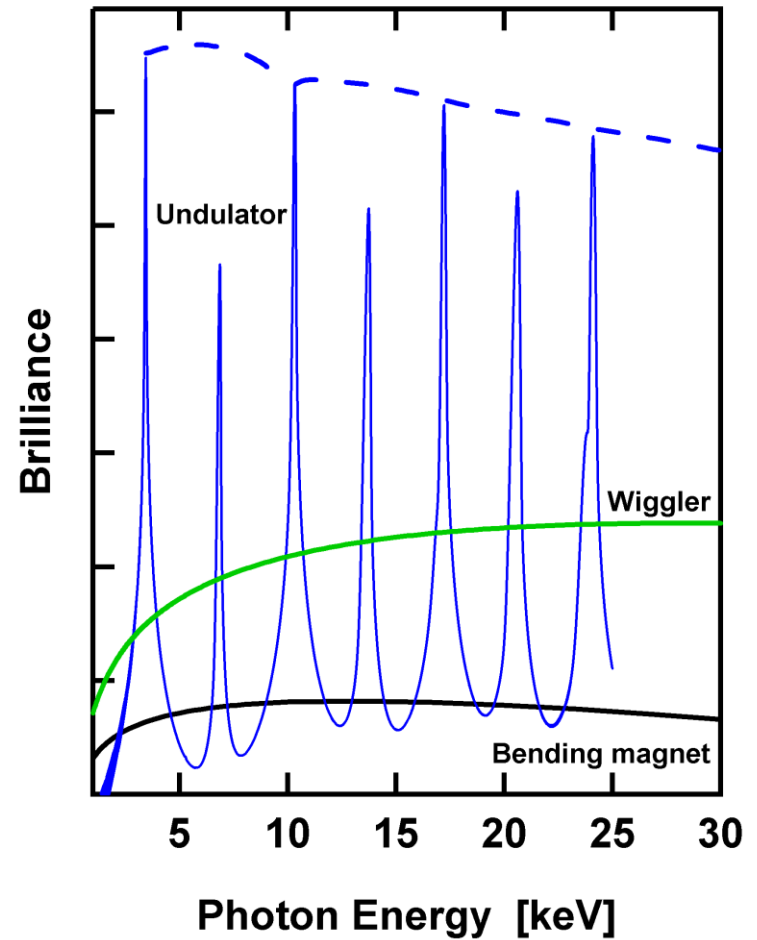
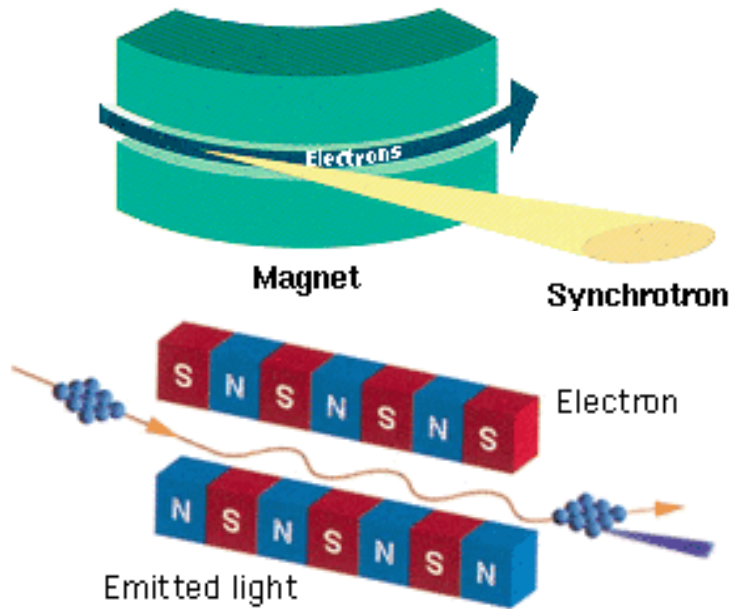
Irradiating topaz and other gems with
electron beams to change the colour

3. Synchrotron Light Sources



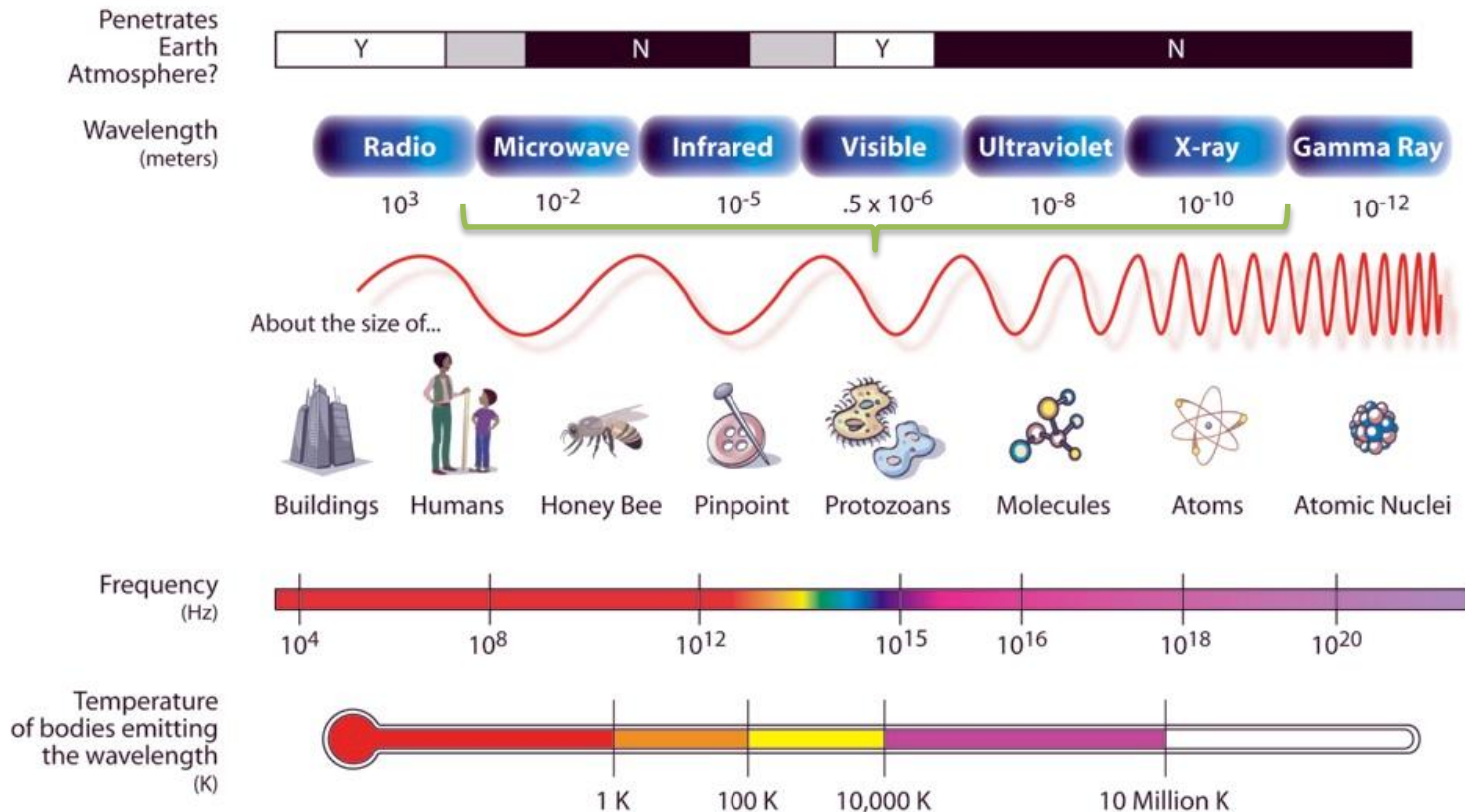
Image courtesy of ESRF

Synchrotron radiation is emitted by charged particles when accelerated radially



Produced in synchrotron radiation sources using bending magnets, undulators and wigglers

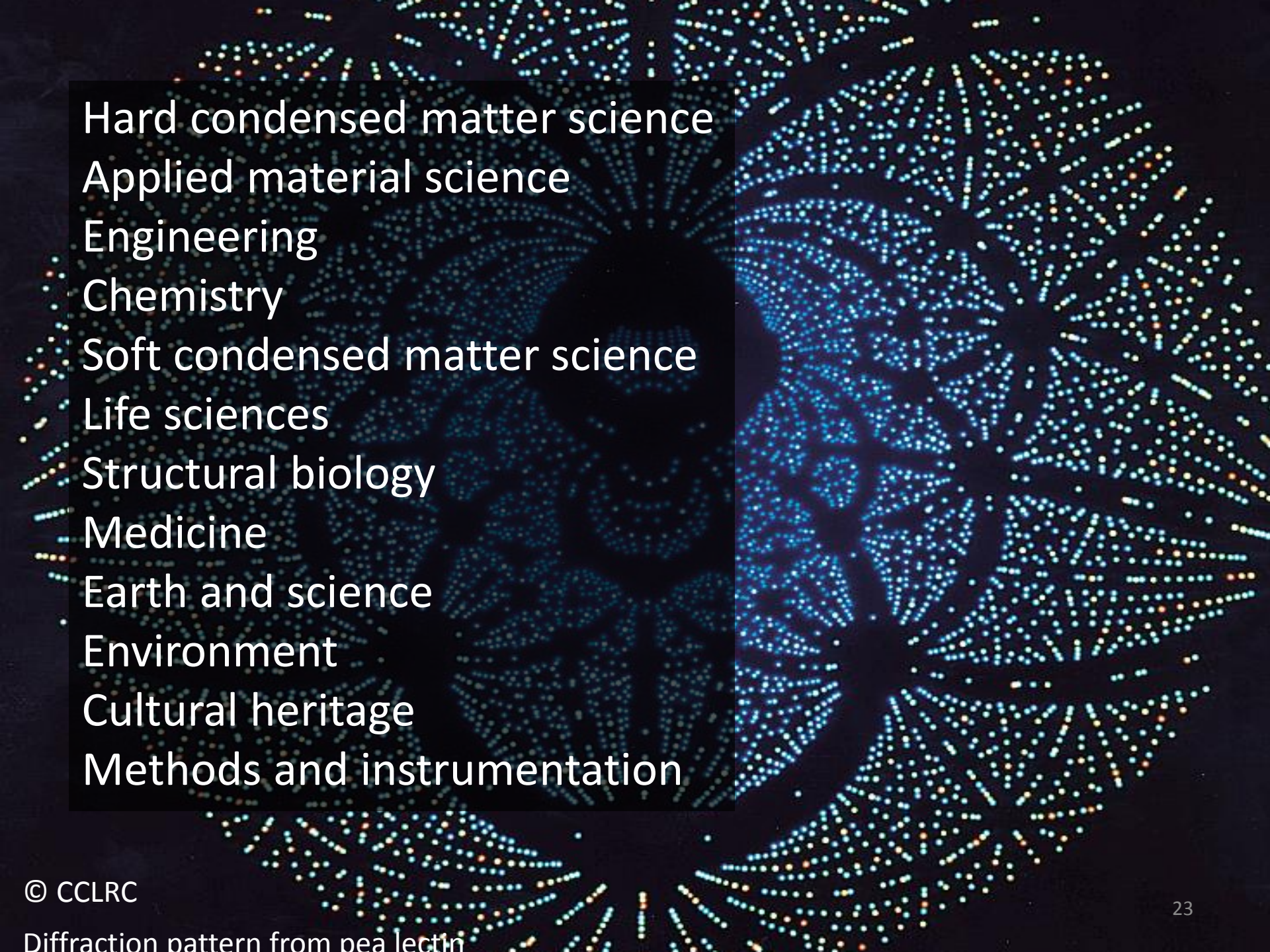
THE ELECTROMAGNETIC SPECTRUM



Synchrotron radiation: microwaves to hard x-rays (user can select)

High flux = quick experiments!

Pulsed structure = resolution of processes down to picoseconds

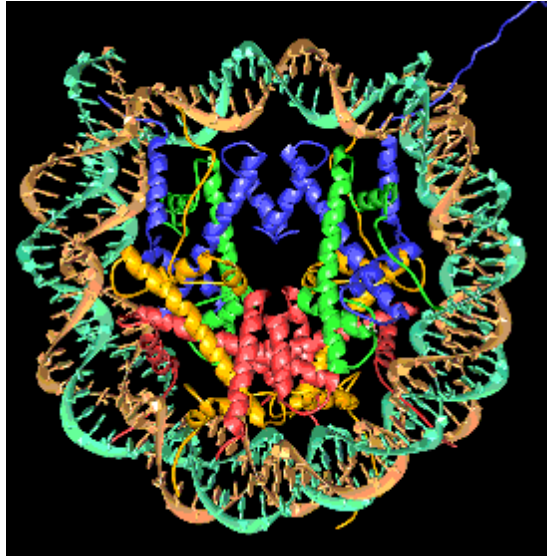


Hard condensed matter science
Applied material science
Engineering
Chemistry
Soft condensed matter science
Life sciences
Structural biology
Medicine
Earth and science
Environment
Cultural heritage
Methods and instrumentation

Synchrotron Radiation Science

Biology

Reconstruction of the 3D structure of a nucleosome (DNA packaging) with a resolution of 0.2 nm



Archeology/Heritage

A synchrotron X-ray beam at the SSRL facility illuminated an obscured work erased, written over and even painted over of the ancient mathematical genius Archimedes, born 287 B.C. in Sicily.



Using X-Ray induced fluorescence

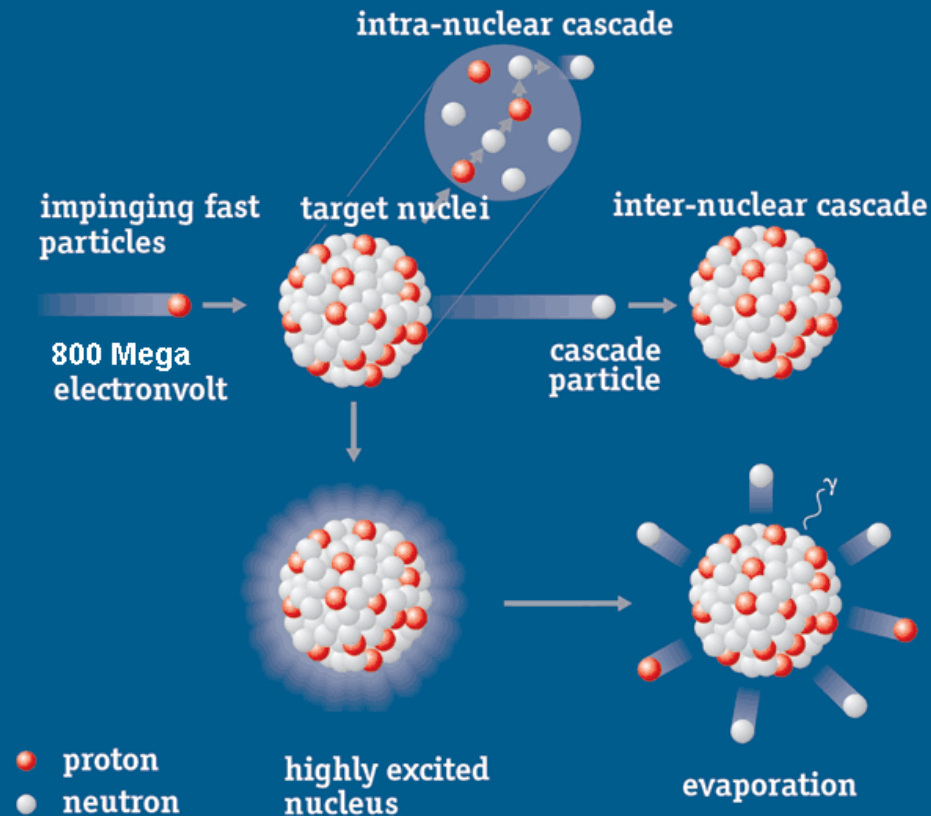
4. Neutron Spallation Sources



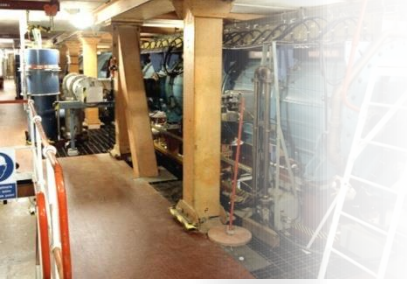
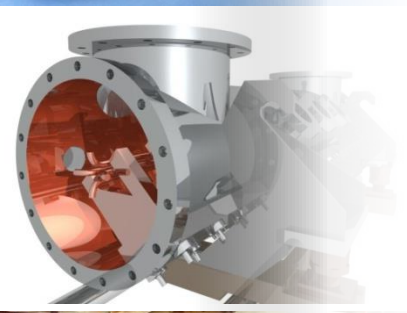
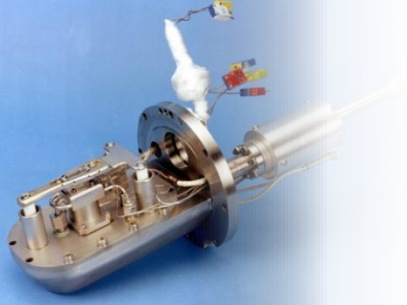
<https://youtu.be/VESMU7JfVHU?t=21>

‘Neutrons tell you where atoms *are* and what atoms *do*’

Spallation



ISIS Accelerators and Targets



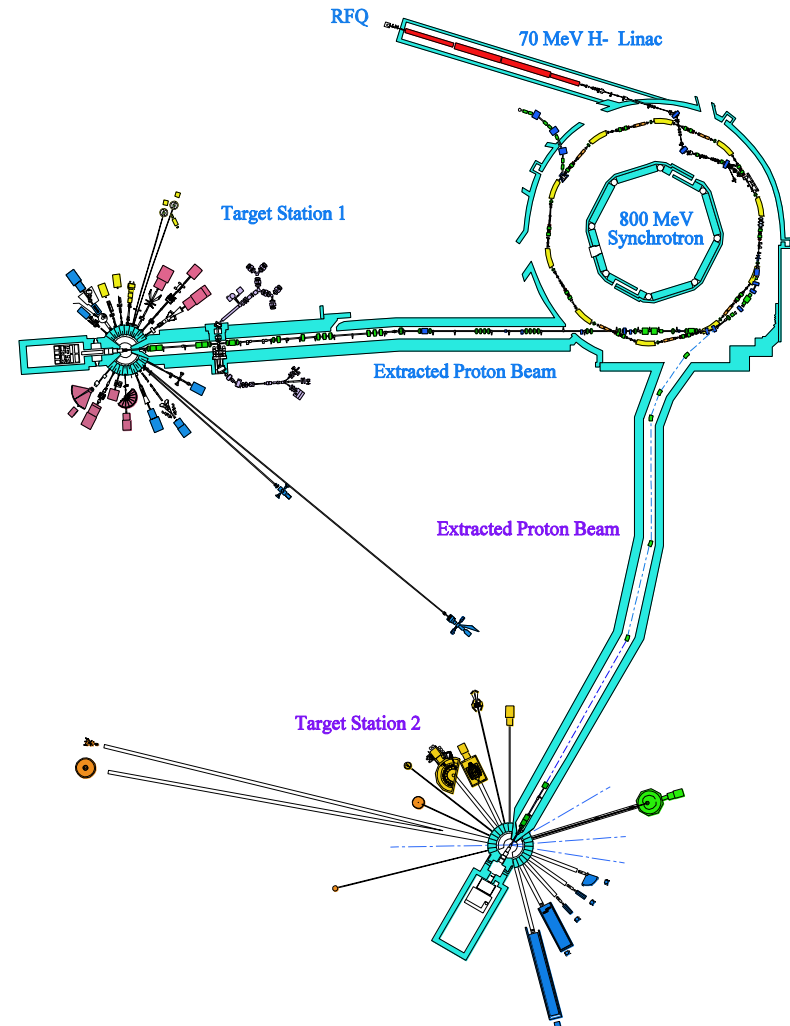
- H⁻ ion source (17 kV)
- 665 kV H⁻ RFQ
- 70 MeV H⁻ linac
- 800 MeV proton synchrotron
- Extracted proton beam lines
- Targets
- Moderators

Pulsed beam of 800 MeV
(84% speed of light) protons
at 50 Hz

Average beam current
is 230 μA (2.9×10^{13} ppp)

184 kW on target (148 kW to
TS-1 at 40 pps, 36 kW to TS-2 at
10 pps).

$$P = 800[MV] \cdot 230[mA] = 184[kW]$$



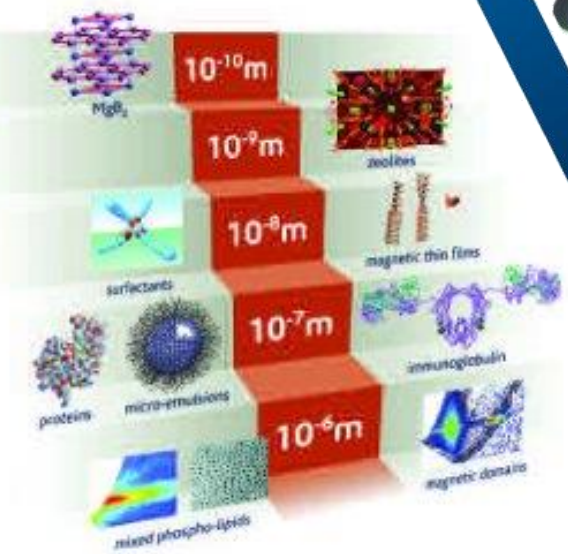
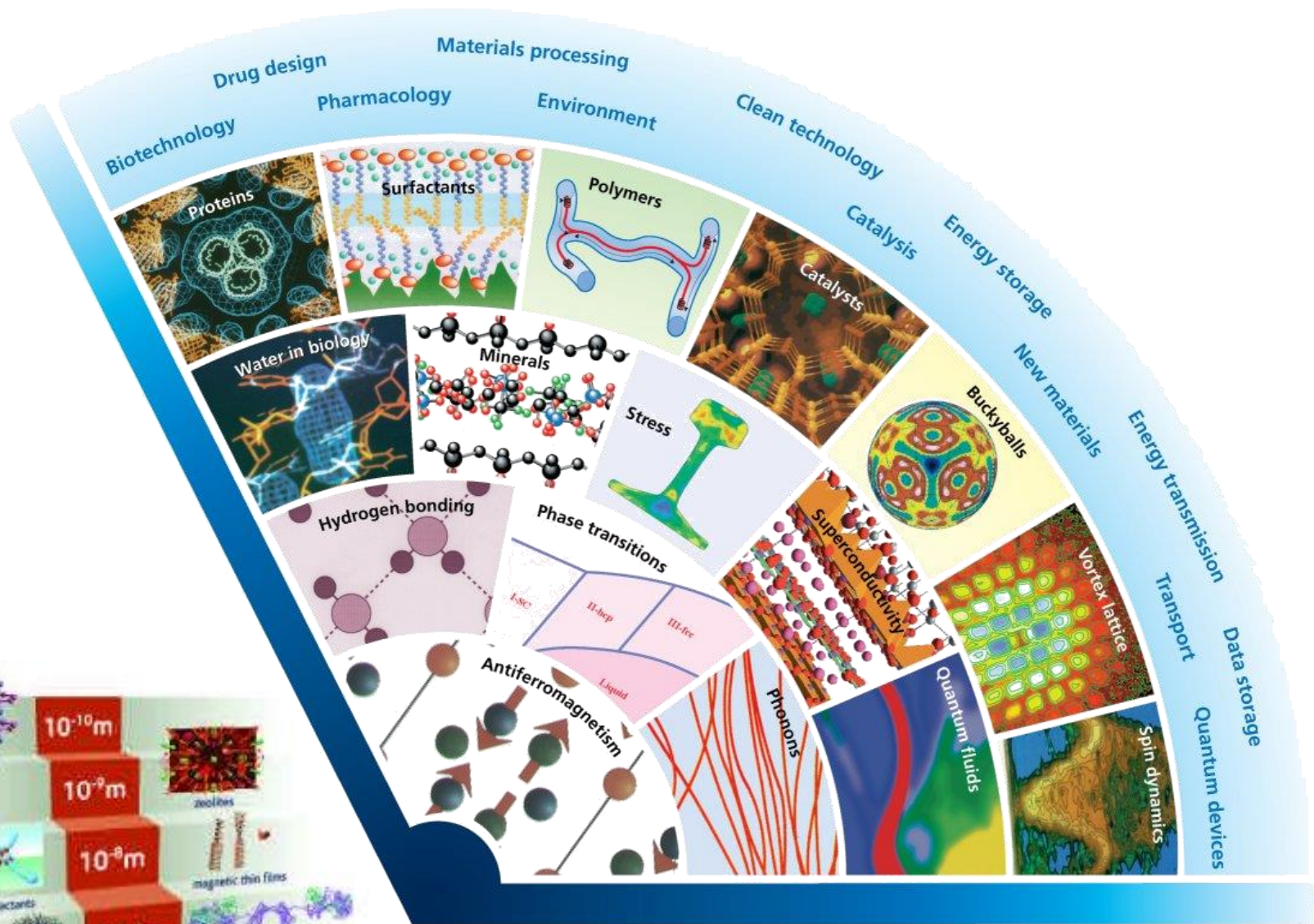
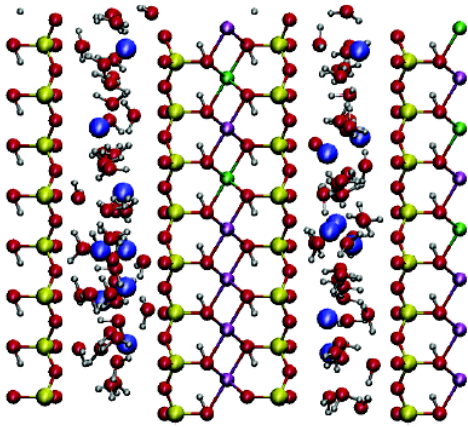
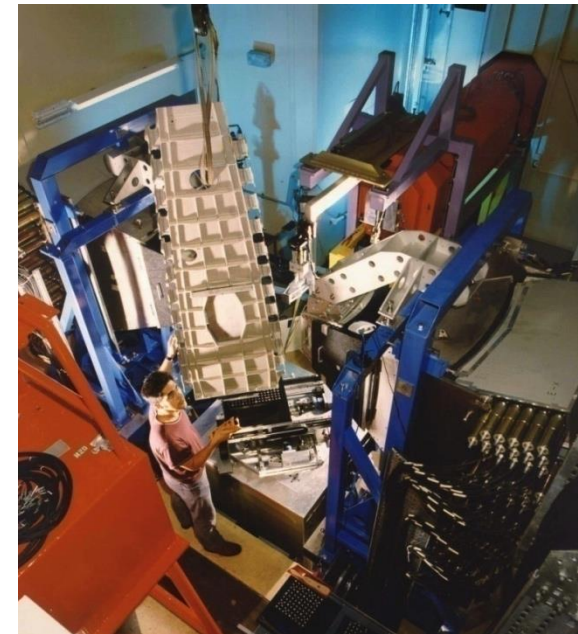
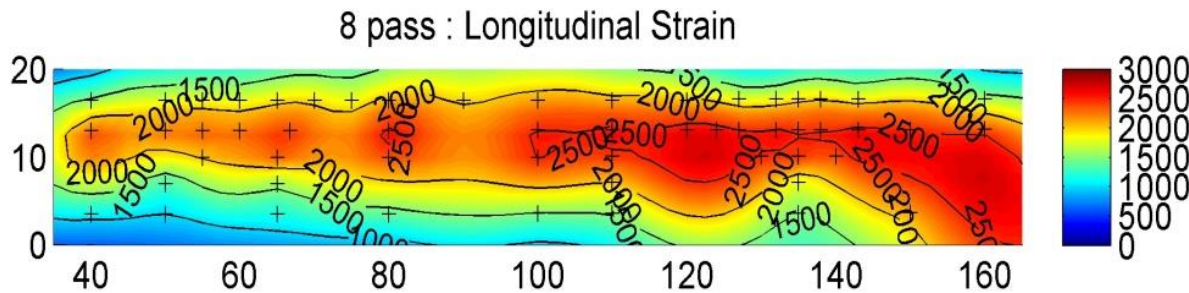


Image courtesy ISIS, STFC.

Understanding the build up of Asphaltenes in oil pipes

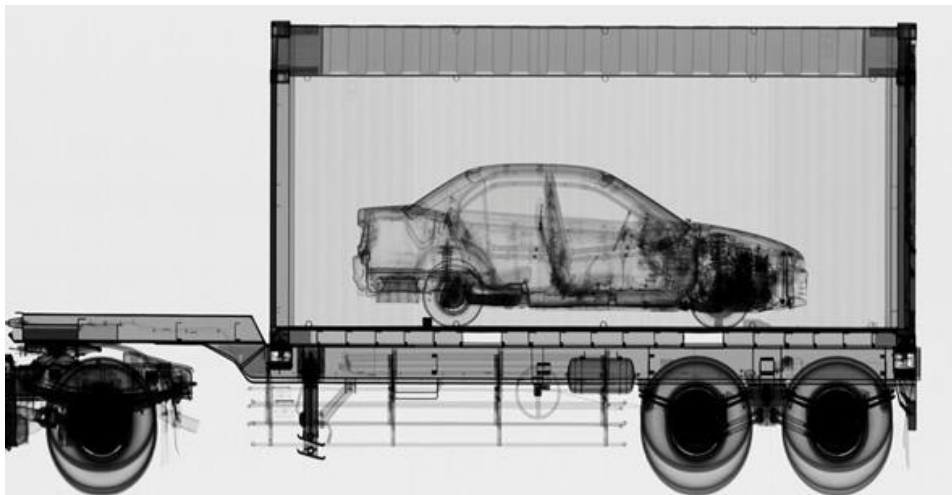


Stresses in Airbus A380 Wing



5. Energy and Security Applications

Cargo scanning



Cargo containers scanned at ports and border crossings

Accelerator-based sources of X-Rays can be far more penetrating (6MV) than Co-60 sources.

Container must be scanned in 30 seconds.

Image source: Varian medical systems

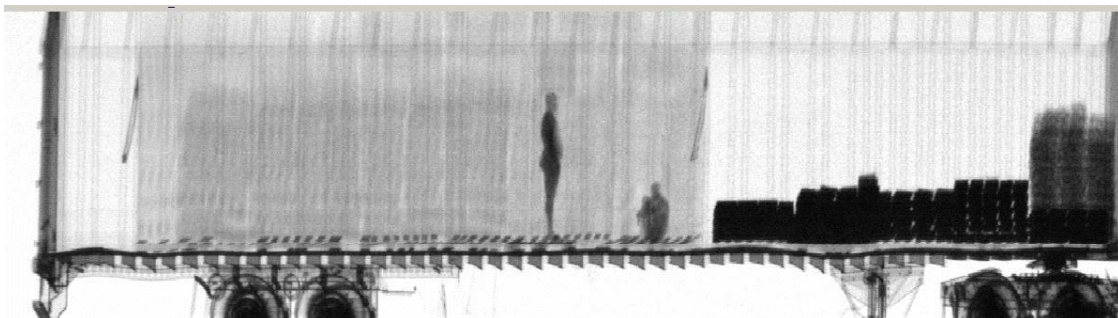


Image: dutch.euro

Materials testing for fusion

Source: IFMIF.org

“deuterium-tritium nuclear fusion reactions will generate neutron fluxes in the order of $10^{18} \text{ m}^{-2}\text{s}^{-1}$ with an energy of 14.1 MeV that will collide with the first wall of the reactor vessel”

International Fusion Material Irradiation Facility (IFMIF)

40 MeV

2 x 125mA linacs

CW deuterons, 5MW each

Beams will overlap onto a liquid Li jet

To create conditions similar to in a fusion reactor

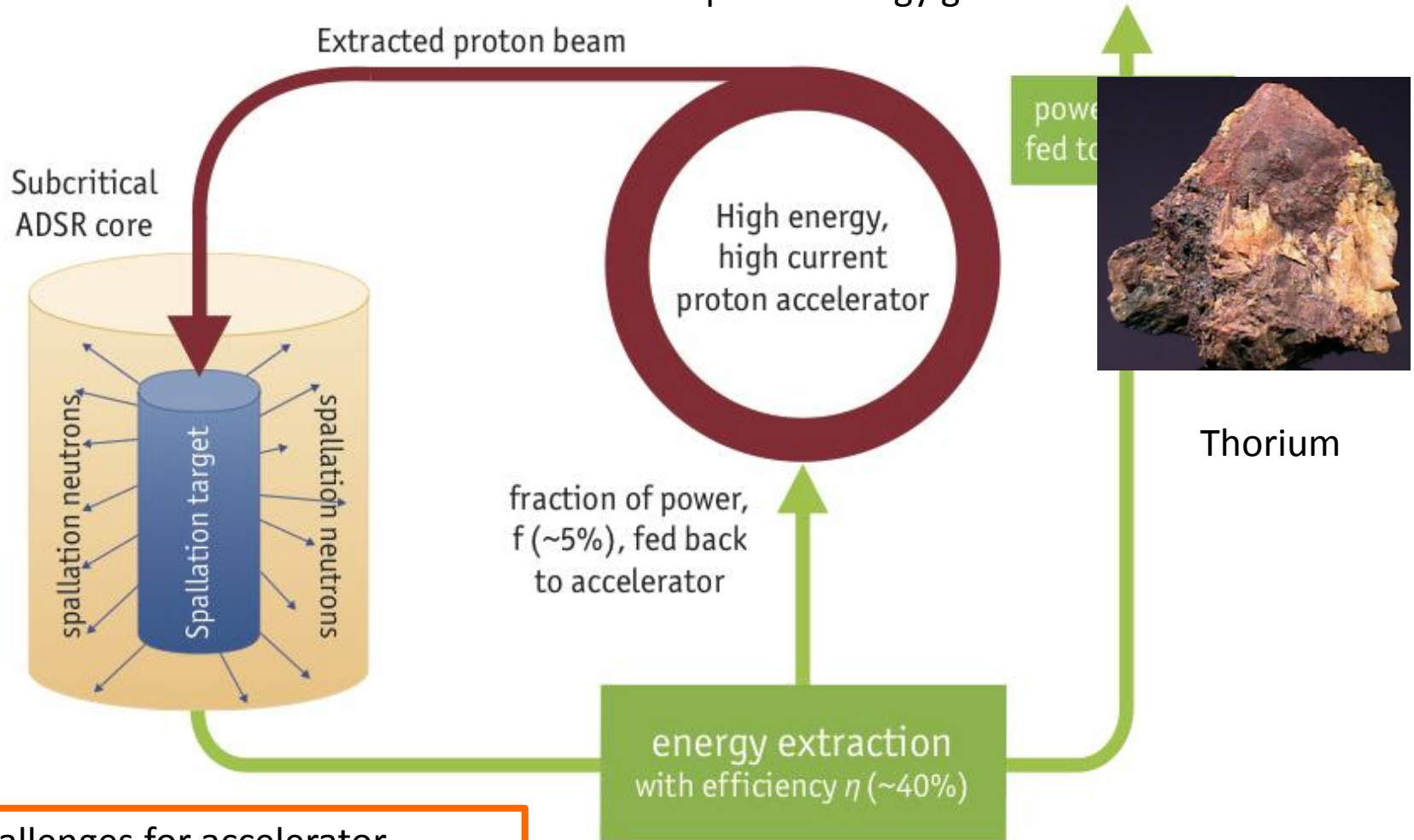
To de-risk IFMIF, first a test accelerator
'LIPAc' is being built



Installation of 'LIPAc' test accelerator has started in Japan

Accelerator Driven Systems

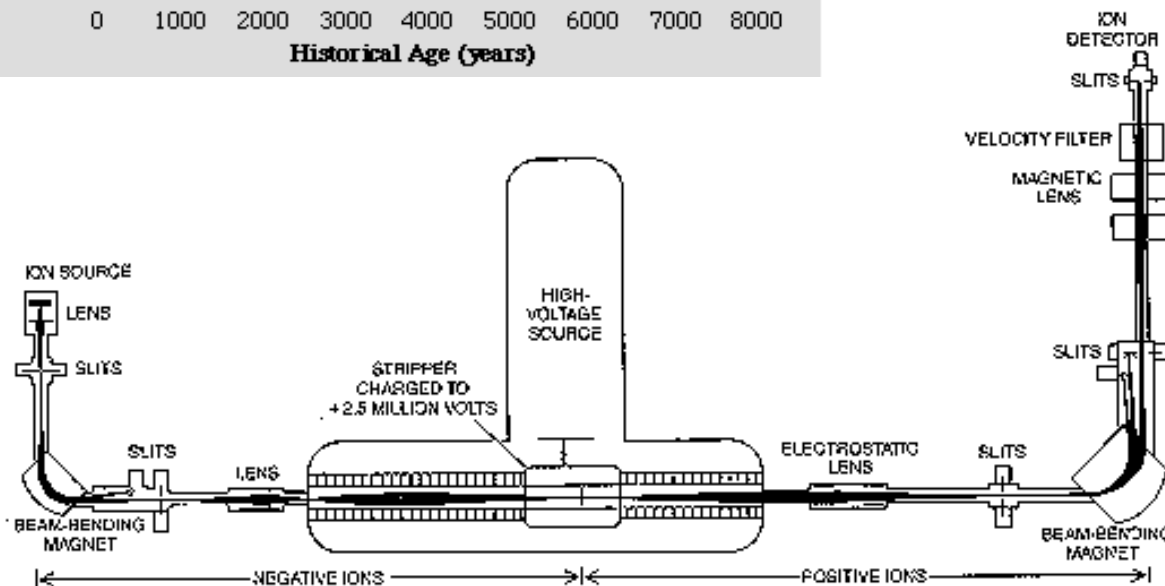
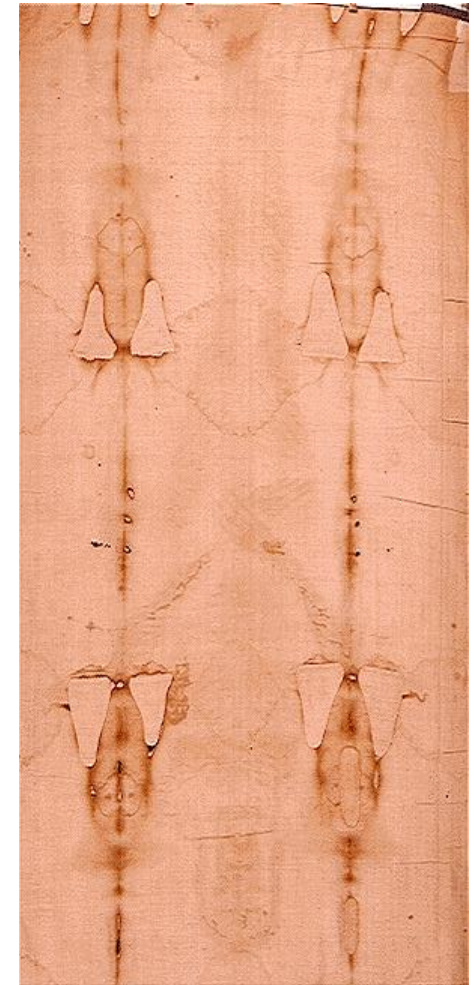
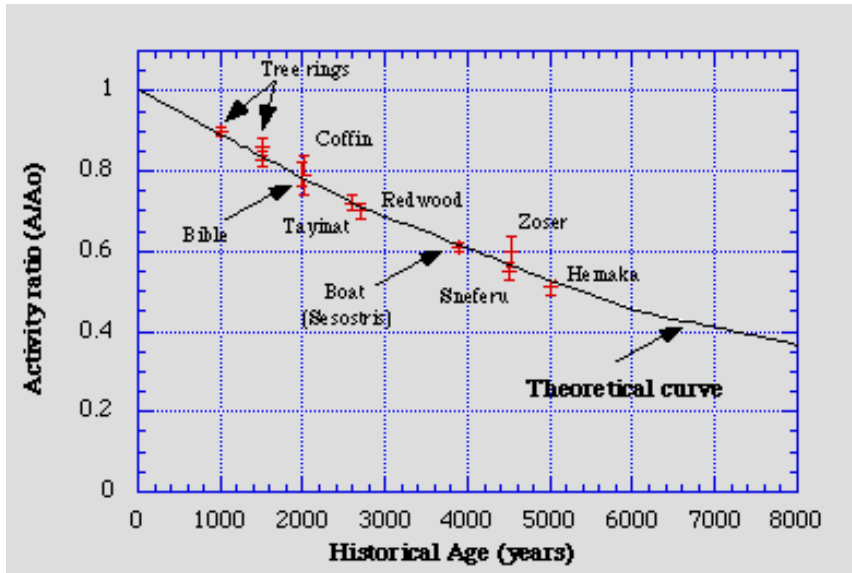
Transmutation of nuclear waste isotopes or energy generation



Major challenges for accelerator technology in terms of beam power ($>10\text{MW}$) and reliability

6. Historical and cultural applications

Radiocarbon Dating



For more accuracy, isolate C-14 from other isotopes
"AMS" = Accelerator Mass Spectrometry

Accelerators can study art

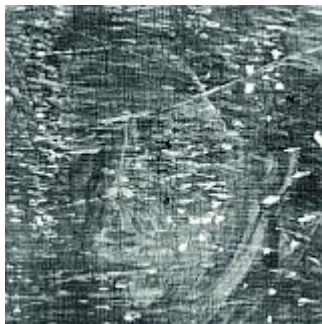


This painting “Patch of grass” by Vincent van Gogh was the first one analysed by a particle accelerator

Patch of Grass, spring 1887, F583/JH1263, KM 105.264 (30,8 x 39,7 cm), Kröller-Müller Museum
(Photo: Rik Klein Gotink)



It showed a portrait of a woman underneath



Accelerators in archaeology

The interior of samples can be studied using accelerators without destroying them

Pottery from Armenia, dating back to 1300 BC, is set up for a synchrotron experiment

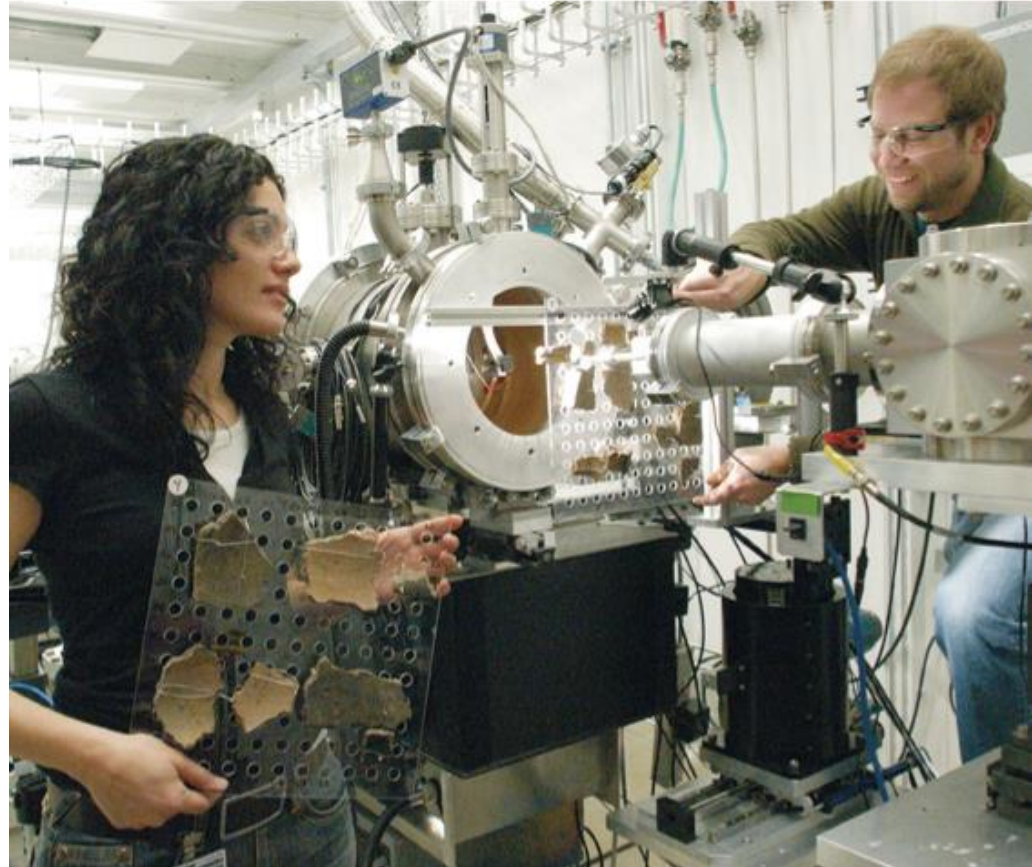


Image: Argonne National Laboratory

Particle accelerators can read hidden text

Accelerators can detect the X-ray 'signature' of iron in ancient pigments

A written message can be revealed even on a folded manuscript which is too brittle to open

This method has also been used to analyse manuscripts and paintings that have layers of information from different authors

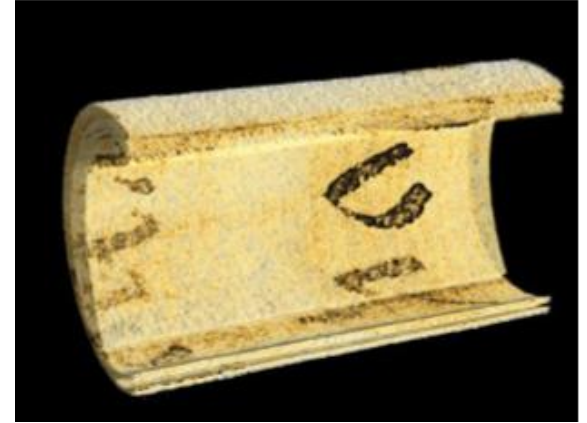
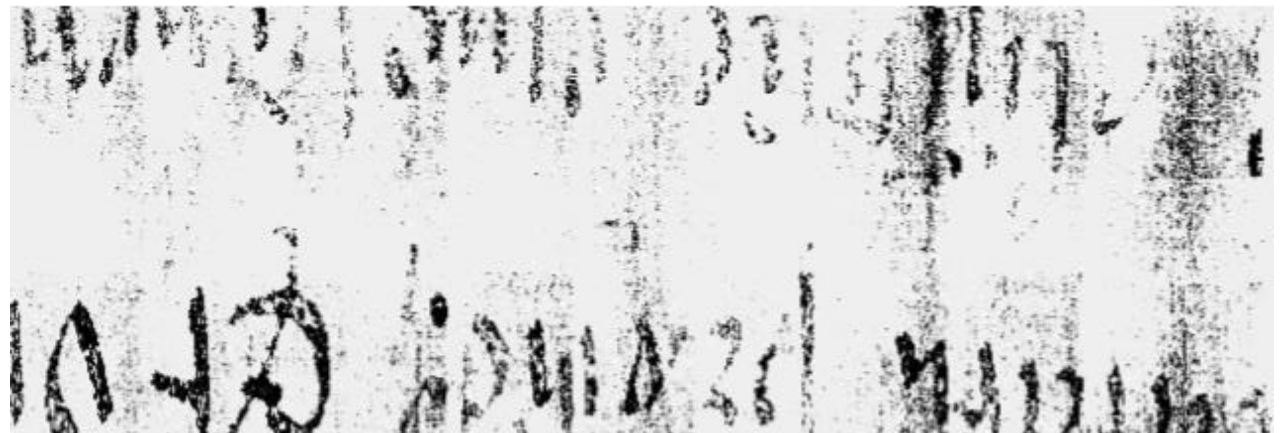


Photo: Graham Davis & Tim Wess



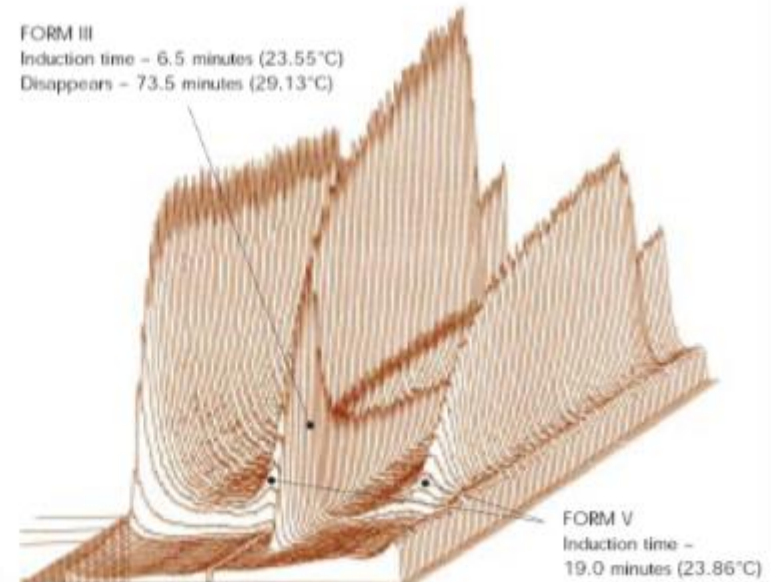
Accelerators can make food taste better

NEW INSIGHTS INTO **CHOCOLATE**



Of the six possible crystal forms, the fifth (form V) produces the best quality chocolate

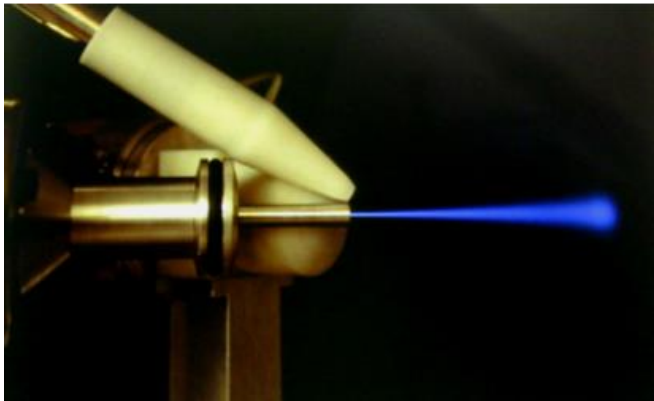
Cadbury used X-rays from a particle accelerator to study how cocoa crystallises



Accelerators can help spot art forgeries

Ion Beam Analysis shows us the chemical composition of pigments used in paint

This allows art historians to compare them with paints available to artists like Leonardo da Vinci



Finally, just one more application...

Detecting wine fraud

Use ion beam to test the bottle of “antique” wine – chemical composition of the bottle compared to a real one.

“In a recent and spectacular case, American collector William Koch sued a German wine dealer, claiming four bottles – allegedly belonging to former U.S. president Thomas Jefferson – purchased for 500,000 dollars, were fake. The case has yet to be settled.”

- <http://www.cosmosmagazine.com>



Next time someone asks you what accelerators are for...

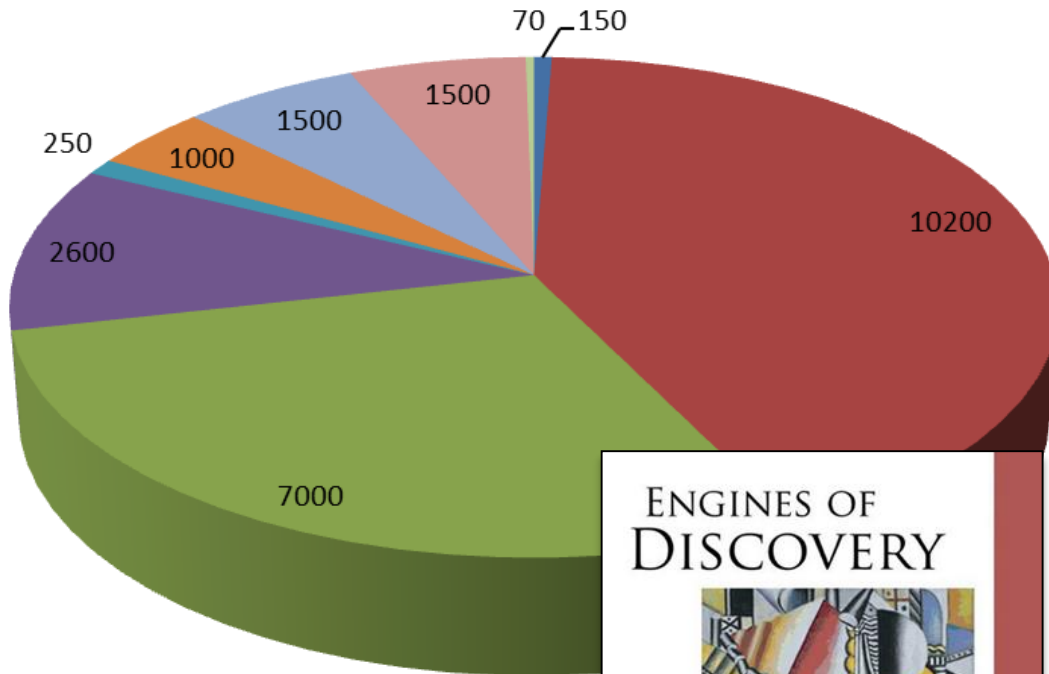
“A beam of the right particles with the right energy at the right intensity can shrink a tumor, produce cleaner energy, spot suspicious cargo, make a better radial tire, clean up dirty drinking water, map a protein, study a nuclear explosion, design a new drug, make a heat-resistant automotive cable, diagnose a disease, reduce nuclear waste, detect an art forgery, implant ions in a semiconductor, prospect for oil, date an archaeological find, package a Thanksgiving turkey or...

...discover the secrets of the universe.”

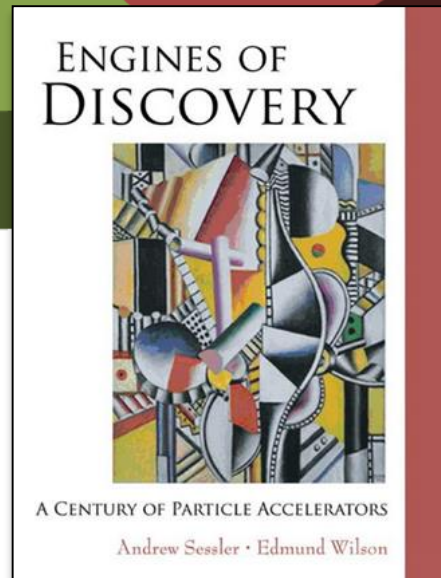


-Accelerators for Americas Future
Report, pp. 4, DoE, USA, 2011

Accelerators in the world >24000



- High Energy Accelerators of more than 1 GeV
- Ion implantation
- Electron cutting and welding
- Electron beam and X-ray irradiators (sterilization)
- Ion Beam analysis (including AMS)
- Radioisotope production (including PET)
- Non destructive testing (including security)
- Neutron generators (including sealed tubes)
- Synchrotron radiation



**Engines of Discovery.
A Century of Particle Accelerators.
Andrew Sessler, Edmund Wilson**

Source (2007):

<http://www.worldscientific.com/worldscibooks/10.1142/6272>